Balloon-deployed probes for Venus

Image: SSTL / ESA

Considered in the context of the

European Venus Explorer

mission proposal

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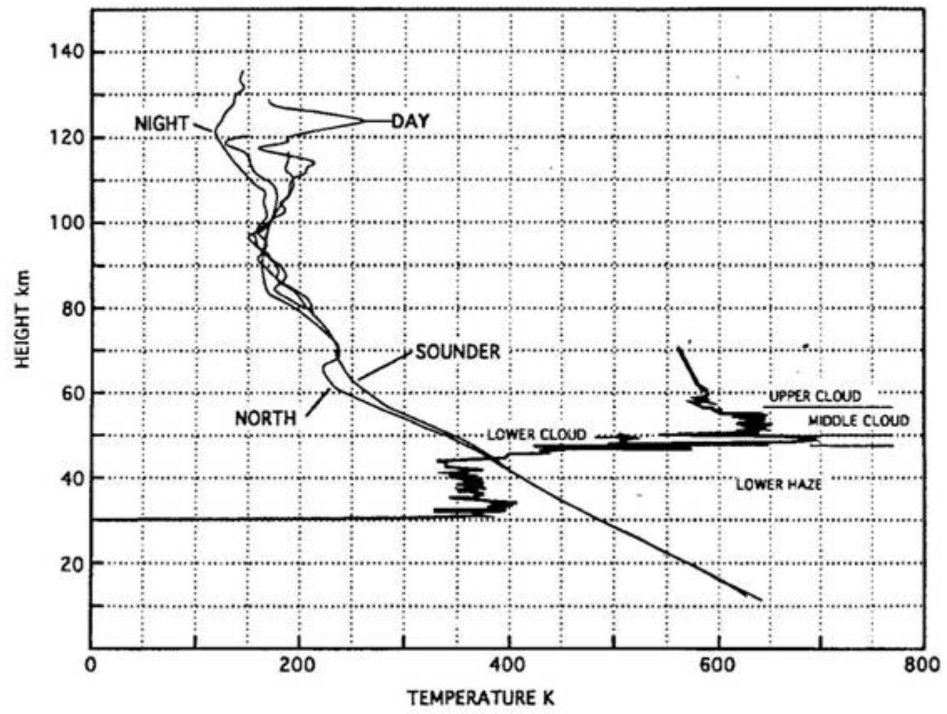
Overview of this talk

- **The Atmosphere of Venus**
- **100 g Microprobes**
- **1-2 kg *imaging* probes**
- **Advantages of different Venus probe concepts.**

Venus Atmosphere

- **96% Carbon Dioxide**
- **Surface Temperature ~450 °C**
- **Surface pressure ~92 bar**

- **Clouds encircle the planet**
  - **Cloud base at ~47 km altitude (100 °C, 1.5 bar)**
  - **Top of main clouds ~ 65 km (– 30 °C, 0.1 bar)**
  - **–Defined as optical depth = 1 in thermal IR**
  - **–Haze layers up to >80 km altitude**



Infrared transparency windows

- CO_2 is greenhouse gas
  - Transparent in visible, opaque in most of infrared.
  - However, there are some gaps in the absorption spectrum
  - 1.01, 1.18, 1.7, 2.3 μm
- At these wavelengths, there is some thermal emission from deep atmosphere and from surface, which escapes to space.
- Main source of attenuation is scattering at cloud droplets
  - H2SO4 cloud droplets are highly reflective at <2.5 μm – so there may be >50 scattering events for a photon leaving the surface.
- Suggestive of cumulus clouds, indicating moist convection
- **LOTS OF SPATIAL VARIABILITY => WE WANT *MULTIPLE* VERTICAL PROFILES THROUGH CLOUDS**

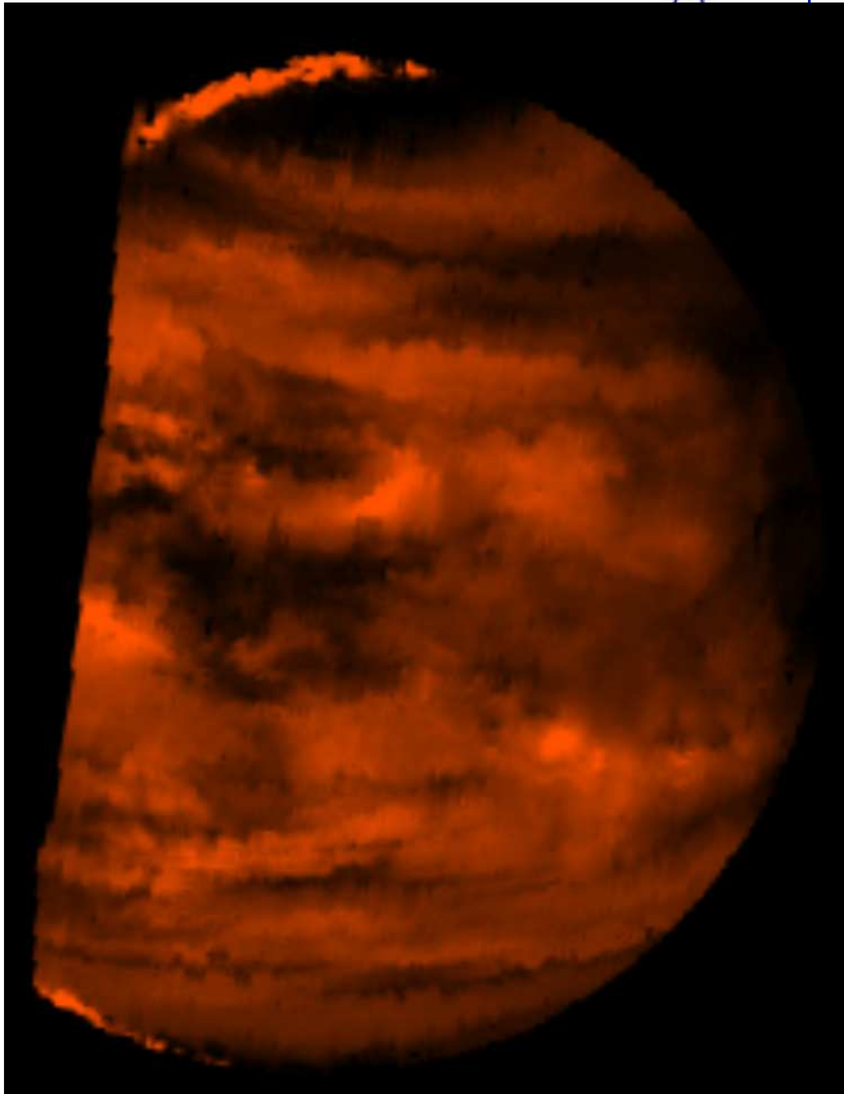
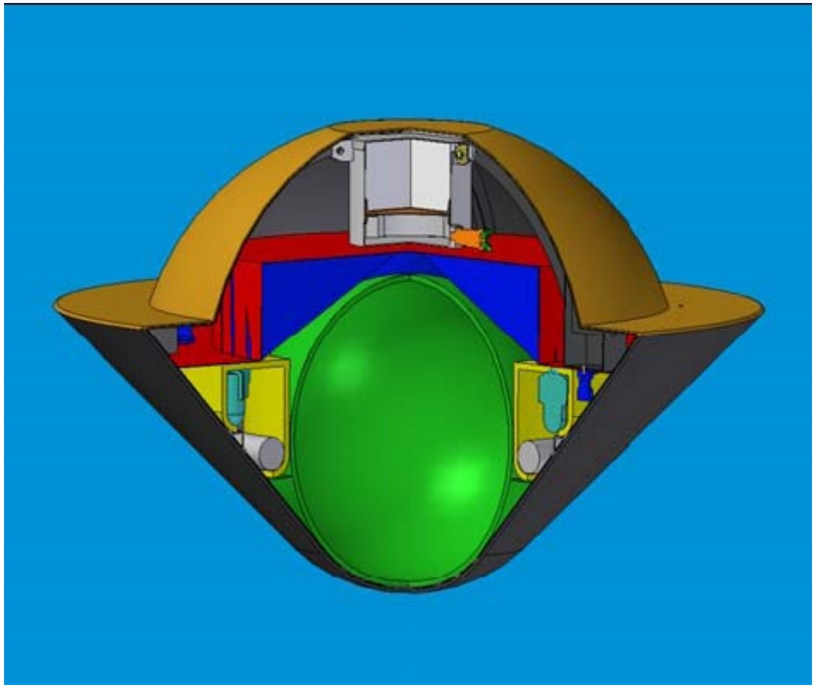


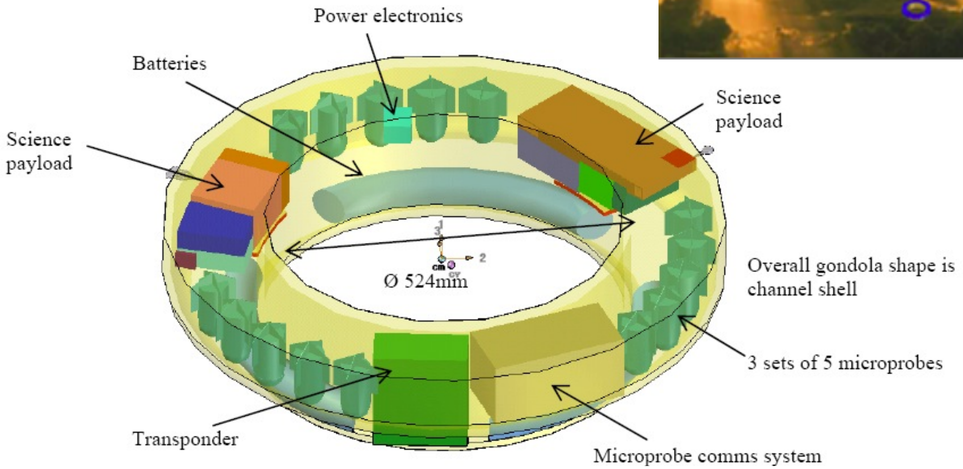
Image: Galileo NIMS (NASA)

ESA VEP TRS

(**V**enus **E**ntry **P**robe **T**echnology **R**eference **S**tudy)

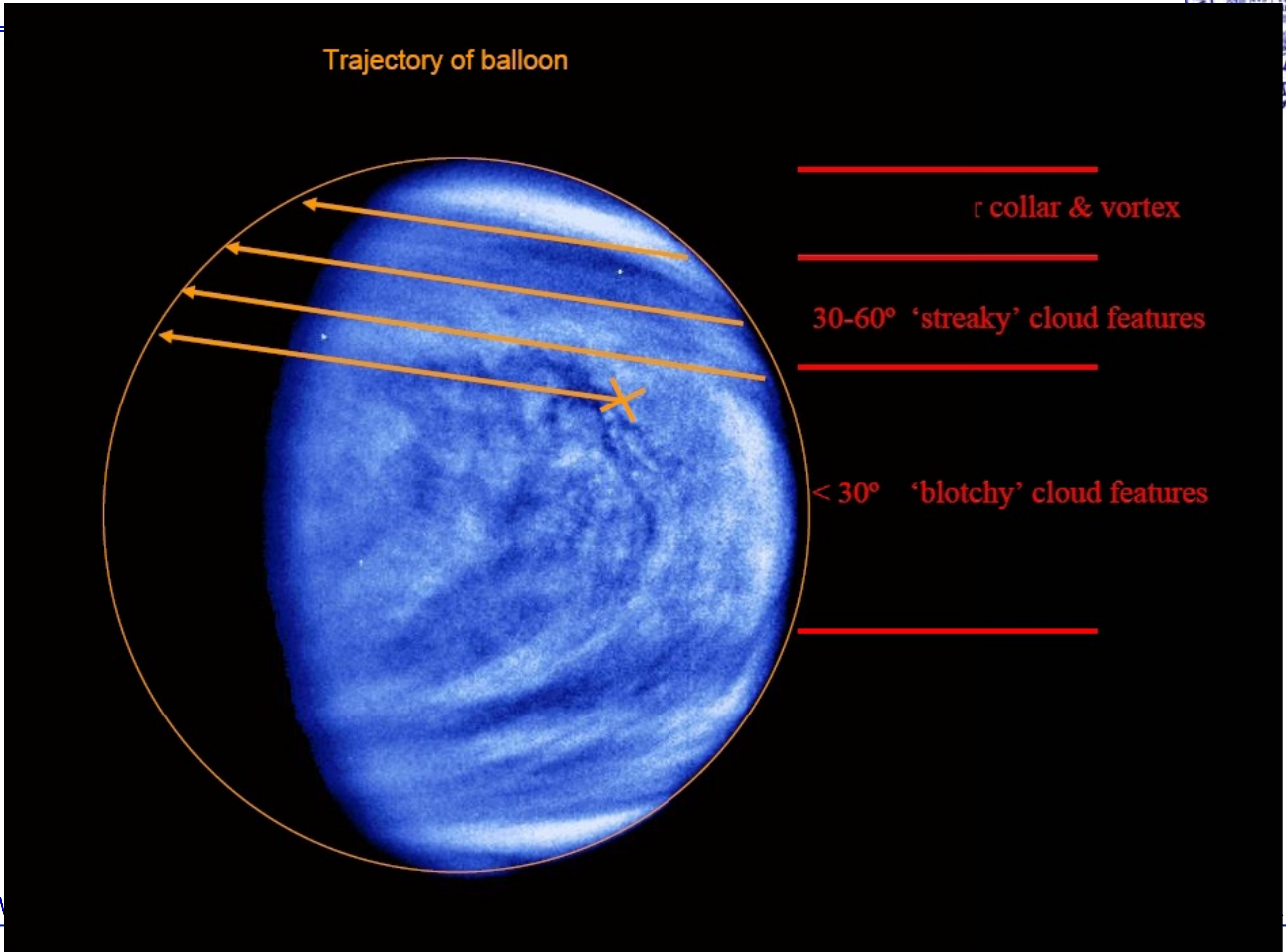
- **2 Orbiters (low circular orbiter, elliptical orbiter for data relay)**
- **1 balloon (55-60 km altitude, i.e. -10 to 20 °C, 0.5 – 1 bar)**





(left) Balloon as stowed in entry vehicle, and (right) layout of balloon gondola. From M van den Berg & P. Falkner, "Study overview of the Venus Entry Probe", SCI-AP/2006/173/VEP/MvdB, 2006. Study by SSTL Ltd., UK.

Take advantage of winds to explore the planet!



Part 1: ESA VEP TRS - microprobes

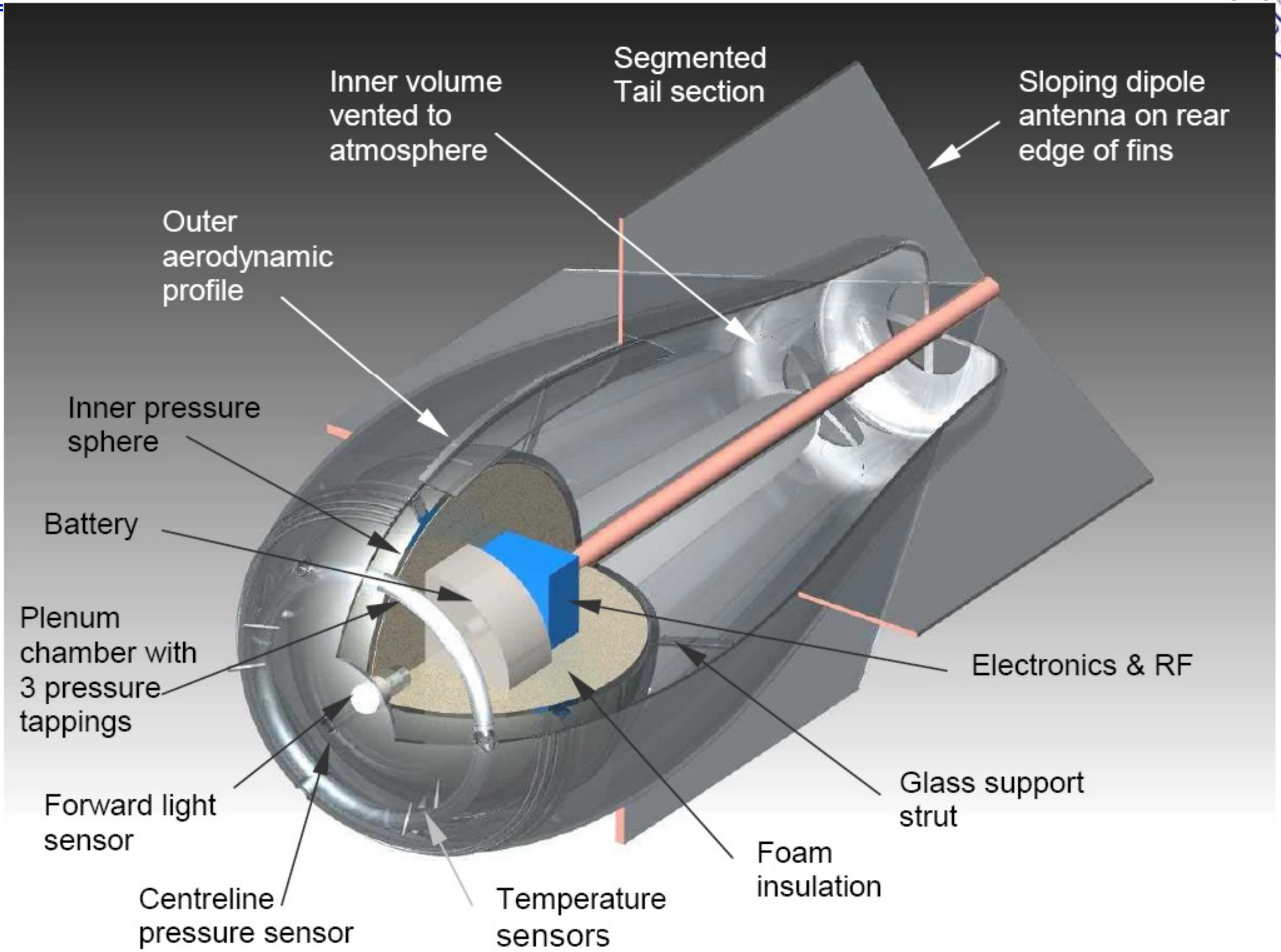
- **Study funded by ESA, with Qinetiq as prime contractor, Oxford U as sub-contractor**
- ***Microprobes – weighing 100 g each – are dropped from balloon. All communications are via balloon***
- **Assumed use of normal 'mil-spec' electronics**
  - **Termperature range –55°C to +125°C**
- **When microprobes reach surface, they are (1) very hot, and (2) very far from balloon (<300 km), due to wind shear.**
  - **According to Ralph Lorenz, 1998, probes < 350 g will never be able to reach surface while electronics <100 °C)**
- **Therefore, payload focuses on 20 – 60 km altitudes, i.e. cloud and sub-cloud layer.**
- **Payload mass budget of 10 g does not allow for sophisticated chemistry investigations.**
- ***Therefore, payload is focussed on atmospheric dynamics & radiative balance.***
  - ***Pressure, temperature, light flux (up & down, solar & thermal IR)***

  Note that this reveals also cloud structure (from light flux measurements)

  Admittedly, simple contact gas sensors could also be included, eg SiC gas sensors

QinetiQ

ESA VEP TRS - microprobes



Probe is 46 mm diameter x 110 mm long; Mass is 100 g.

100 g microprobes – flight profile

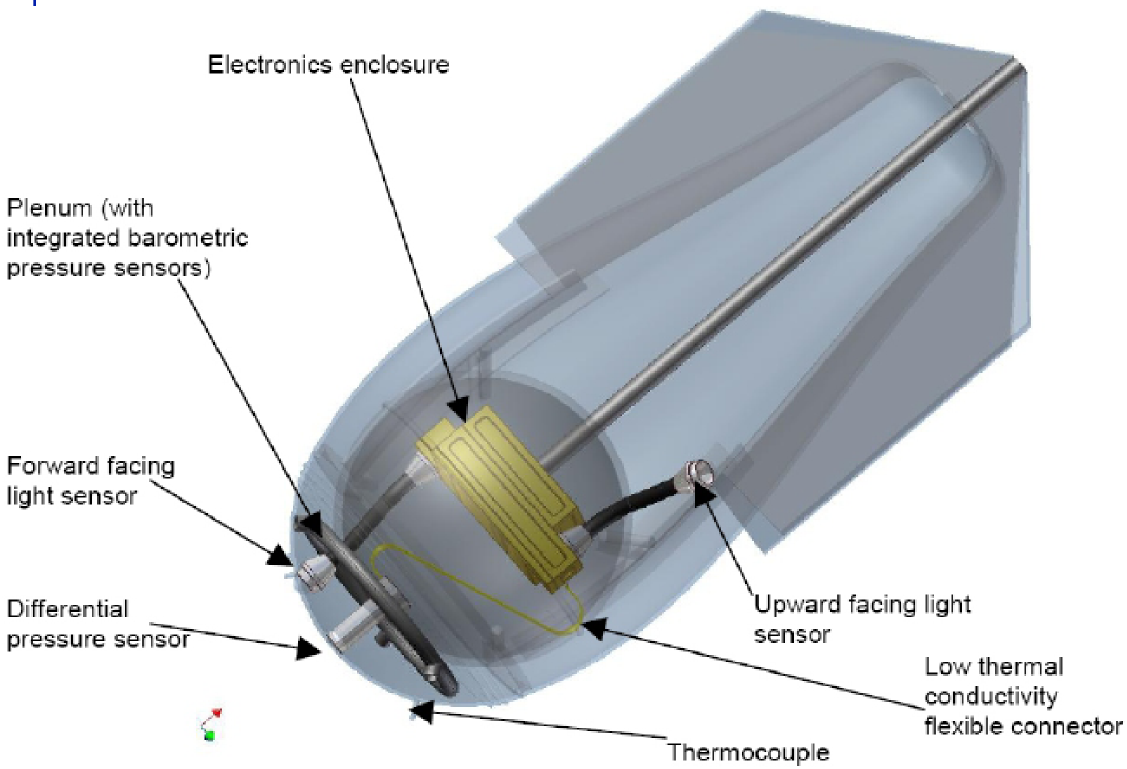
Microprobes are tracked from balloon, to measure winds.

- **Range of microprobes is obtained using a 'ping' system (accuracy: ±150 m)**
- **Direction of arrival of radio signal is obtained using a phased antenna array aboard balloon. (DOA Accuracy: ±0.5 °)**
  - **Mass of this comms package on balloon, inc. antenna array: 1.5 kg.**
  - **Flight test of this comms/tracking system: Summer 2007**

- **Probes drop rapidly, in order to maximise vertical coverage.**
  - **Max drop speed is Mach 0.5 (u ~ 125 m/s).**
  - **50 minutes later, when the probe reaches surface,**
    - **it has decelerated to 10 m/s.**
    - **It is up to 300 km from balloon (depending on wind profile)**
  - **Measurement rate is determined by required vertical resolution – once per 100m.**

- **Great advantage of 100 g microprobes: this allows a vast number of microprobes: e.g. 20 microprobes + comms package = 3.5 kg**

Microprobe payload – 10 grams



Sensor	Number	Mass (g)	Description
Temperature	2	2	Thin-wire thermocouples, with a reference temperature sensor (e.g. Platinum resistance thermometer inside the probe. Accuracy ~0.1 K
Pressure	3 abs. + 1 diff.	0.7	4 micromachined silicon diaphragm pressure sensors. Each sensor covers a different pressure, so the exact number will depend on the final drop height. Accuracy ~1% of reading
Wide-band light sensors (cloud detection and solar radiation budget measurements)	2	2.8 g (includes light guides)	Silicon photodiode (providing coverage from ≈250 to 1100nm), and thermopile for coverage to 4um. The sensors would be coupled to the atmosphere via a quartz fibre optic light guide and mounted to provide up and down views with a condensing lens. Accuracy ~1% for Si sensor
Electronics Box	1	2.7	interface to DHU
Flex connectors	2	0.2	Copper-on-Kapton interface to p, T sensors. Low thermal conductivity.
Total		**8.4 g**	

- **Payload has high TRL!**
  - –**MEMS pressure sensors, thermocouples, Si photodiodes**

Part 2: Imaging probes

- **Why?**
  - **Images of the surface, at several wavelengths, would yield reflectivity at several wavelengths & hence mineralogical constraint.**
    - ***However, the downwelling light needs to be well-characterized, in order to get good reflectivity data.***
  - **Images of the surface useful for characterising morphology.**
    - ***However, the illumination is very diffuse***
  - **Added thermal mass is needed in order to reach surface, and to carry larger communications system**
  - **With added mass, we might as well carry a more sophisticated chemistry package, and a camera, as well as p, T, light flux sensors.**

Study funded by STFC (UK), study by Qinetiq, definition by Oxford Univ, Imperial Univ, UCL, Open Univ. in preparation for EVE proposal.

Venus radiative transfer

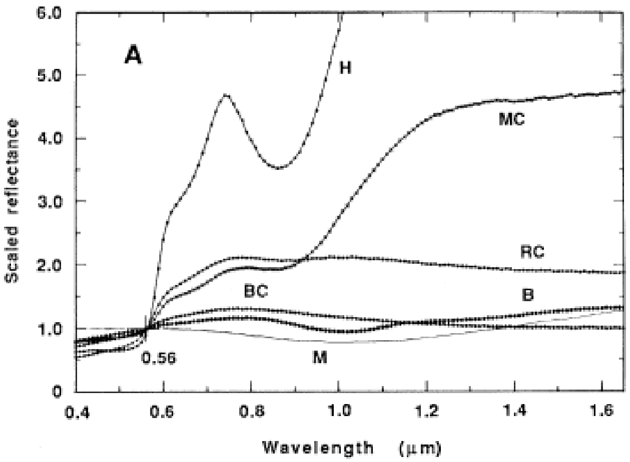
Light from the surface of Venus is attenuated by:

- **Gaseous absorption**
  - –CO_2, H_2SO_4, H_2O are all greenhouse gases, opaque in most of IR
- **Rayleigh Scattering**
  - –There is so much CO_2 that Rayleigh scattering is important for visble wavelengths.
- **Scattering from cloud particles**
  - –Main cloud deck is at 48-65 km, with hazes up to 90 km
  - –There may be some near-surface aerosols. Fog? Dust? 'Silt?'

- **So: in visible wavelengths, surface is only visible from <1km altitude (Moroz, PSS 2002)**
- **Surface is visible at 1.02 µm (IR window region) from sub-cloud altitudes.**

Imaging Probes: Science goal

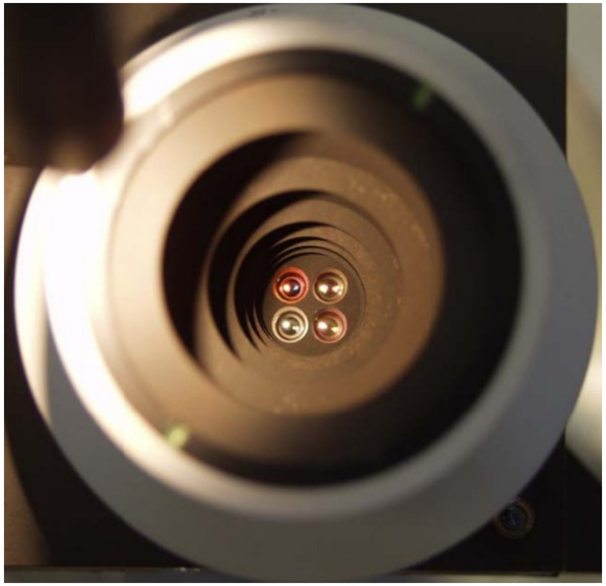
- **Obtain reflectivities at a few different wavelengths in 0.5 – 1.0 µm range to constrain surface composition**
  - **–e.g. Pieters et al., Science, 1986**
- **Image, at high resolution, the surface morphology.**
  - **–Lava channels / tectonic features**
  - **–Beware that incoming light is diffuse, but some spatial contrast was possible on Huygens despite diffuse light.**
  - **–Will not be clear whether observed contrast is due to composition or topography variation.**



Reflectance spectra of Venus candidate minerals, scaled to 0.56 µm.
Pieters et al., Science, 1986

Imaging probes: camera payload

- **Imaging = high data rate** - especially for a rapidly-dropping probe!
- We suggested using a camera based on the Venus Monitoring Camera (VMC) on Venus Express.
  - One CCD, 1000 x 1000 pixels
  - Four objective lenses cast an image of the same scene onto different quadrants of the CCD
  - Each lens has a different spectral bandpass filter (eg. 0.7, 0.8, 0.9, 1.02 μm).
  - 1 Mpixel x 12 bits/pixel x 0.5 Hz x 1/20 compression (lossy!) = ***300 kbit/sec***



Images from VMC website at Max Planck Institute, Germany

Imaging probes: chemical payload

- **Miniaturised Mass Spectrometer**
  - **Mass spectrometers < 100 g are possible**
  - **Low TRL if all infrastructure is included (pumps, etc)**
  - **Calibration difficult in rapidly changing thermal environment**
  - **Exciting, but not currently well defined for this mass range (<100 g)**

- **SiC gas sensors**
  - **Can operate at high temperatures >800 K**
  - **Sensitive to CO, SOx, H_2O, and others TBD**
  - **Very light (<50 mg for array of sensors)**

- **For this study, we assumed an array of 16 SiC gas sensors**

  (Mass of sensor arrays = 50 mg)

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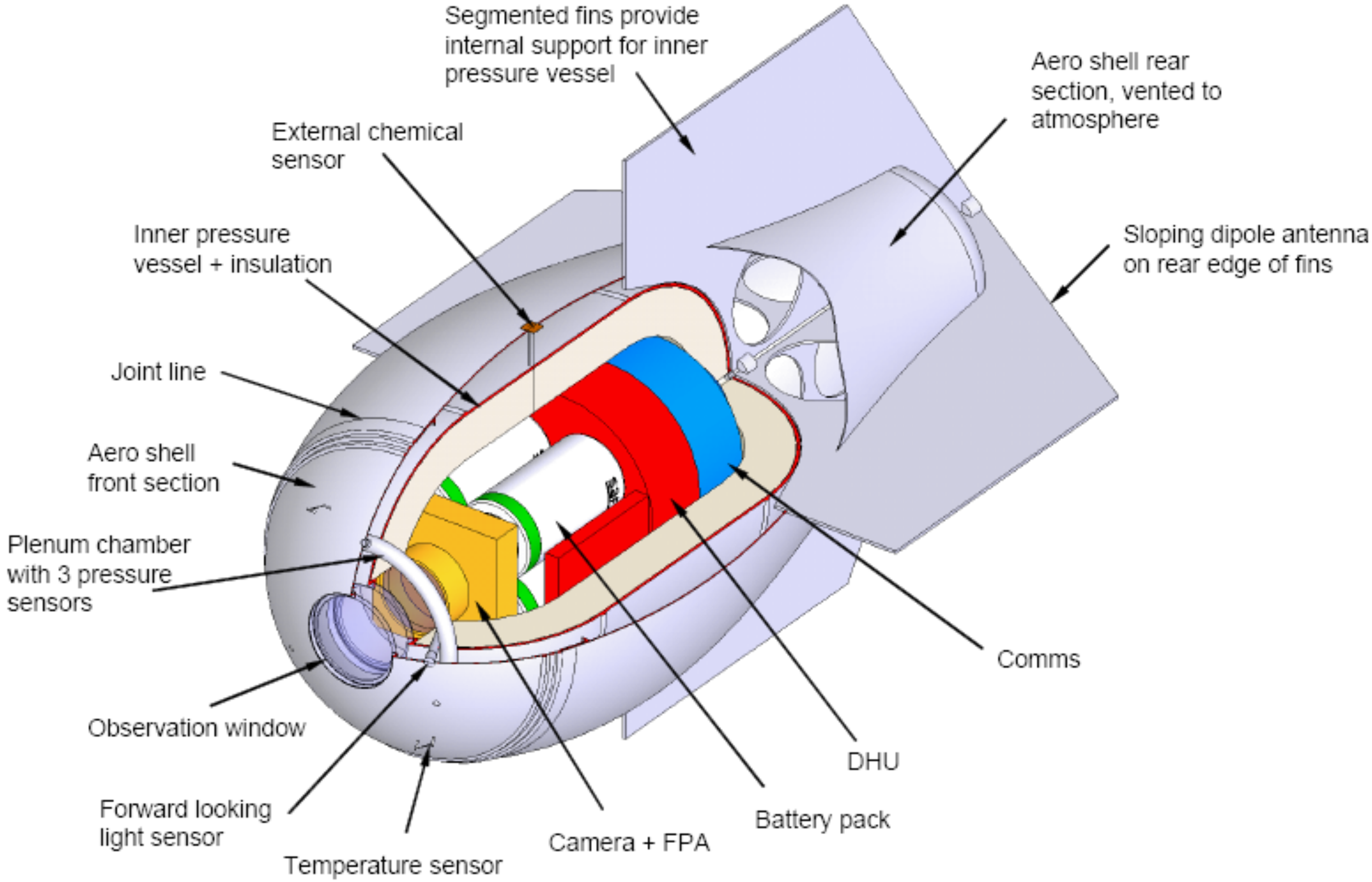
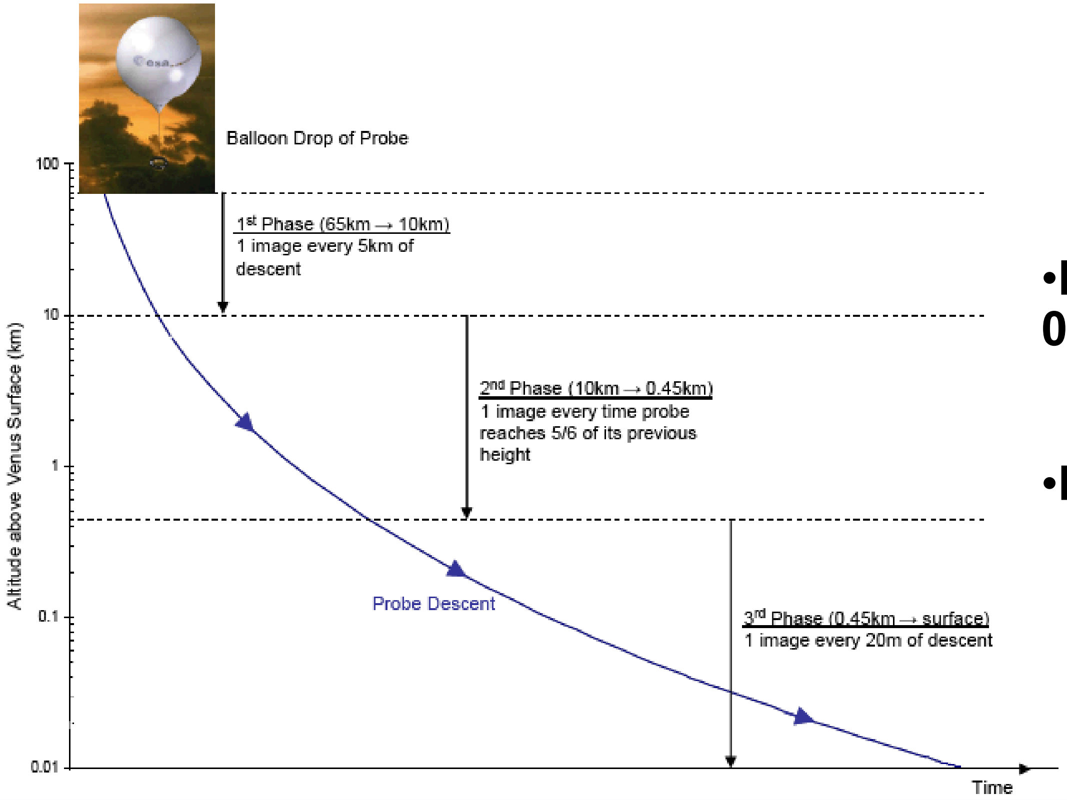
Imaging probe design



Probe is 127 mm diameter x 305 mm long; Mass is 2 kg.

Imaging probes - flight profile

- **Descent must be *fast* in order to minimise the temperature at the electronics (and CCD) when the probe reaches the surface.**
- **However, it is also vital to obtain good ambient pressure measurements during descent, for atmospheric profiles. Requires subsonic flow at pressure tappings.**



•Maximum speed reached: Mach 0.5 (~125 m/s) Early in descent.

•Descent speed at surface: 10 m/s

Imaging probes – thermal design

- **Different insulation materials considered:**
  - **–Rohacell (*k ~0.0035 W m*$^{-1}$ *K*$^{-1}$) and aerogel (*k ~0.001 W m-1 K-1*).**
  - **–Final design uses 15 mm thickness of aerogel insulation**
  - **–Final design uses <100 g of paraffin wax (phase change material @ 50°C)**

- **Thermal loads considered:**
  - **–Power dissipation from DHU (~1W)**
  - **–Power dissipation from comms system (10W peak dissipation, <0.3 W ave)**
  - **–Radiative heat leak through viewing window (<0.1 W, thanks to spectral bandpass filter)**
  - **–Heating of exterior from environment; from radiative flux; from aerodynamic heating…**

- **Assume drop height of 60 km ($T_{initial}$ = - 10°C)**
- **When probe reaches surface, CCD is still at 51°C**
  - **–Low temperature = low noise = good performance of CCD.**

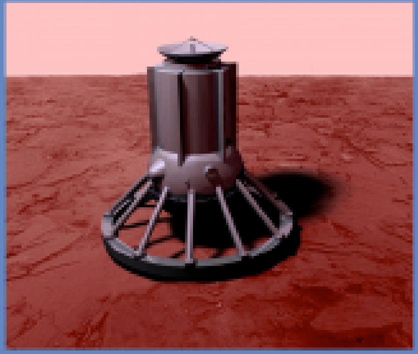
- ***This is a simple feasibility study: further optimisation is possible!!!***
- ***1kg probe mass is possible, albeit with somewhat lower image resolution.***

Conclusion: Microprobes, Miniprobes, or Probes?

- **Microprobes (100 g)**
  - –**Allow MANY (>> 10) vertical profiles**
  - –**Good for dynamics; radiative balance; cloud structure**
  - –**Not great for chemistry**
  - –**Do not reach surface (while still communicating).**
- **Miniprobes (~1-2 kg)**
  - –**1-6 probes may be deployed from balloon.**
  - –**Surface imaging possible.**
  - –***Could* carry a complex miniaturised chemistry package.**
- **Direct-entry large probe (>20 kg).**
  - –**Allows wider distribution of probes around the planet**
  - –**Comms direct to orbiter, or direct-to-Earth**

European Venus Explorer (EVE)

An in-situ mission to Venus



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A proposal for the Cosmic Vision 2015-2015 ESA plan